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WAR MEDICINE AND SURGERY

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CHEMICAL WARFARE.

Most of the latest information on chemical warfare is not generally available, and one can only guess how much the articles published in current medical journals on this subject are out of date. There are good reasons, however, why it is worth while summarizing such information as can be obtained. In the first place, it is probable that we are kept relatively well informed about the prevention and treatment of gas casualties, and these aspects are of great importance. It was stated in 1939 that no agent was known which was more effective than mustard gas in sending men to the hospital, or more effective than phosgene in poisoning the air.[5] If this is still true, the literature can give valuable help, since the treatment of poisoning by these two gases has been described in great detail. Again, one of the main risks to be run by a population attacked with gas is the danger of panic; and fear, which inspires panic, can be greatly reduced by a knowledge of the facts. It should therefore be more generally known that the difficulties of attacking with gas are great, and the defence against it is relatively good. Moreover, the degree of suffering, the percentage of deaths, and the permanent after-effects of gas compare favourably, from the humanitarian point of view, with the effects of other weapons of warfare.[2] Barcroft has stated, when writing of the possibility of the use of gas in the present war, that there is every reason for precaution, but no reason for dread.[1]

Classification.

There are certain poisons which are not used for offensive warfare, but are nevertheless frequently encountered by an army. The chief are carbon monoxide, nitrous fumes and various screening smokes. The substances deliberately used in chemical warfare may be classified as follows:[3]

Group I (lethal):

(*a*) Vesicants or blister gases: mustard gas, lewisite.
(*b*) Asphyxiants or choking gases: phosgene, diphosgene, chlorine, chloropicrin.
(*c*) Hæmolysant: arseniuretted hydrogen.
(*d*) Paralysants: hydrocyanic acid, sulphuretted hydrogen.

Group II (harassing):

(*a*) Lachrymators or tear gases.
(*b*) Sternutators or nasal irritants.

In addition to this medical classification, there is a military classification into persistent and non-persistent gases.

Mustard Gas.

Properties.

The substance known as mustard gas can be called a gas only when a very elastic terminology is used. Actually one of its most important properties is its stable, liquid nature. Its boiling point is as high as 217° C., so that it is a "persistent" substance, giving off toxic vapour over a long period of time, especially if the weather is cool. An area contaminated by mustard gas may remain uninhabitable for a fortnight, unless it is decontaminated by special treatment.

The liquid, as used in its rather impure state, is dark in colour and has a mustard-like or garlicky odour. This characteristic smell gives us a useful means of detecting the gas, but casualties may be caused by exposure to concentrations so low that the smell is not noticed.

Mustard gas is only slightly soluble in water, but dissolves readily in animal fats. It is therefore absorbed rapidly by the lipoid of human tissues, and its destructive action is almost immediate. It is soluble also in organic solvents such as petrol, methylated spirits, kerosene and carbon tetrachloride. Consequently these are useful for removing liquid mustard gas from contaminated skin.

Mustard gas has a high power of penetration, and the liquid form will soak readily through military clothing and boots. In fact, no wearing apparel as yet discovered is impervious to it. Oilskin and rubber materials give relative protection.

Mustard gas can be rendered non-toxic by hydrolysis, by chlorination or by oxidation. Hydrolysis is slow in cold water; but the action is accelerated at high temperatures, so that clothing can be decontaminated by being boiled in water. The commonest oxidizing agent used to destroy mustard gas is bleaching powder, and the commonest chlorinating agent is chloramine T. Both of these are used in the treatment of mustard gas lesions of the skin.

Methods of Dispersal of Mustard Gas.

Mustard gas can be used in shells or bombs. The latter are more effective, since their thinner wall permits the use of a greater relative amount of chemical. More than half the total weight of the bomb is due to the mustard gas. Mustard gas is also well suited for spraying from containers fastened to the undercarriage of aeroplanes. The viscosity can be adjusted so that the droplets do not shatter.

Mustard gas is heavy as well as being only slightly volatile, and tends to persist after distribution. It freezes at about 7° C., but is still dangerous in the solid state, especially as it then loses its odour. A small amount of the liquid is destroyed by the moisture of the air, but most of it is rendered ineffective by evaporation and dispersal. It is evaporated at a rate which depends on the atmospheric conditions, and is then dispersed by the wind.

Toxic Action.

Mustard gas acts as an irritant that damages the tissues with which it comes in contact. Its most important effects, therefore, are on the eyes, the skin and the respiratory tract. A small amount may be swallowed and cause nausea. It has no important systemic effects, and kills mainly by creating favourable conditions for the onset of bronchopneumonia.

Mustard gas was the most effective chemical used in the Great War. It caused about 80% of the casualties due to gas amongst the British troops. At that time it was distributed only by means of shells; it could now be distributed more efficiently, but sulphonamides are available for the treatment of its main lethal complication.

One of the most important features of its action is its insidious nature. It is not immediately irritant to the skin or the eyes, and can best be detected by the sense of

smell. Even this has limitations: the quantity may be so small as to be odourless, or the smell may be concealed by other substances; in any case, the sense of smell is rapidly fatigued.

Effects on the Skin.—Liquid mustard gas penetrates the skin in two to three minutes; but, even so, hours may elapse before the lesion is detected. Erythema is the first sign, and gradually a vesicle forms within the erythematous area. In the early stages pain is not severe. The contents of the blister usually become infected and ulceration may follow. The effects after exposure to the vapour are similar, but are not so severe. They are most marked on areas that are hot and moist. With the lighter injury, vesicle formation is uncommon; the discoloured skin desquamates and the pigmentation disappears.

Effects on the Eyes.—The destructive action on the eye is, apparently, almost instantaneous. If both eyes of a rabbit are exposed to mustard gas vapour and one is irrigated immediately, the treated eye is affected as severely as the untreated. This may be due to the inefficiency of the irrigating fluid, but, in any case, it shows that quick treatment does not forestall damage to the eye. Symptoms occur from two to forty-eight hours after the injury. The part of the conjunctiva exposed between the lids is affected most. There are lachrymation, extreme photophobia and moderate pain. The conjunctivæ become congested, and the eyelids swell so rapidly that the palpebral fissure is closed.

About twenty-four hours after the lesion first appears, a white band may be seen passing across the exposed conjunctiva and contrasting with the injected areas above and below. The band is caused by œdema compressing the vessels, and is evidence of a severe lesion. As resolution occurs, the white area becomes injected at the same time as the injected areas become normal.

The cornea, at the height of the injury, is grey and lustreless. It may become ulcerated, and some of the severe ulcers may cause permanent opacities.

About 75% of the patients, as judged by experience from the Great War, are only mildly affected and recover in one to two weeks. A further 15% are more severely injured, and show the horizontal white band of chemotic conjunctiva referred to above. They have also a diminution of sensation of the cornea, and a roughening of its surface. Recovery is not complete for about five weeks. The remaining 10% of patients have erosion of the cornea, and require a convalescence of two to three months.

It is now accepted that, once an eye has been injured with mustard gas, a corneal ulcer may develop after a latent period of even ten years. This is due to damage done to the vascular and nerve supply of the cornea. The ulcer is characterized by its situation between the palpebral margins, its comparative indolence, its depth, and the relative mildness of the symptoms. These ulcers are very interesting and striking, but it must be remembered that the percentage of gassed patients who have contracted them since the last war is negligible.

Action on Respiratory System.—The mucous membrane of the air passages may be affected by the vapour of mustard gas, though the small bronchi usually escape. The early effects are rhinitis, pharyngitis, laryngitis and tracheitis. The patient therefore is troubled with sneezing, nasal discharge, sore throat, hoarseness, and an unproductive cough. The great danger, however, is the possibility of developing septic bronchopneumonia. Because this is the commonest fatal complication, the majority of deaths from mustard gas occur on the fourth or fifth day.

Prophylaxis against Mustard Gas.

The eyes and respiratory tract can be protected by a suitable respirator. The fatality rate for mustard gas in the last war decreased from 50% to 2% when the troops obtained respirators, and became skilled in the use of them. The usual respirator has been designed to give protection from war gases in general, and is effective against all that have so far been encountered, except carbon monoxide and nitrous fumes, ammonia, hydrocyanic acid and arsine. The respirator consists essentially of a tight-fitting face mask connected by corrugated tubing to some form of filter, which is contained in a metal box called the canister. All inspired air passes through the filter, and expired air is forced out through a valve. The filtration is mechanical in the case of certain gases such as the sternutators, which are fine suspensions of solid matter; to deal with other gases, however, use is made of activated charcoal treated with certain metallic salts which act as catalysts; the gas is either absorbed or oxidized. The wearing of a mask reduces efficiency, especially in the performance of fine work. Moreover, gas masks cannot be worn by infants or by certain sick people, and these must be given suitable tents or placed in a gas-proof refuge.

To protect the skin from mustard gas, special clothing has to be worn. This consists of a helmet, oilskin jacket and trousers, rubber boots and rubber gloves. One disadvantage of this outfit is that it is cumbersome, and a compromise has to be made when freedom of movement is necessary. Further, the clothing itself becomes dangerous whenever it is contaminated—dangerous to others if worn in a confined space, and dangerous to the wearer if kept on too long.

Decontamination of Persons Affected by Mustard Gas.

It is proposed that first-aid posts should be responsible for the decontamination of those people who have been affected by gas, but not otherwise injured. If the patient is wounded as well as gassed, he should be sent straight to hospital and decontaminated there. In America gasoline filling stations are to function, if necessary, as improvised decontamination centres. They have certain advantages for this work: they are very accessible; they have good facilities for washing; and they are often constructed of impervious material.

The detailed procedure for cleaning mustard gas casualties[4] is simple in principle, but much practice is required before it can be carried out efficiently. The work must be completed quickly, for mustard gas does most of its damage in the first ten minutes. The second requirement is carefulness; the attendants have to remove the mustard gas from the casualty without contaminating themselves. It is well known that quickness and carefulness are often conflicting requirements.

The cleaning department usually consists of four sections—a stripping shed, where the outside clothes are discarded, an undressing room, where the remaining clothes are removed, a shower room, and a dressing room. It is an advantage to have an airlock between the undressing room and the shower room. The attendants in the stripping shed must have full protective clothing—that is, oilskin suits, Wellington boots, special gloves, helmet, hood, and gas masks. The attendants in the undressing room need similar protection, but it is an advantage for them to wear ordinary rubber gloves, since the special gloves limit finger movements too much. Rubber gloves alone are not a good protection from mustard gas, but the attendants take the precaution of dipping their gloved hands into bleach solution about once every five minutes. The attendants in the shower room are sufficiently protected by boiler suits, Wellington boots and rubber aprons. If the doctor works in the shower room and the dressing room only he does not require protective clothing. It is very exhausting to work in gas-proof outfits and a rest is necessary after about half an hour.

It should be emphasized that quickness of treatment is imperative. On arrival at the stripping shed the patient stands in a tray, which is filled to a depth of about one inch with a thick suspension of bleach. His outer clothes, and any other clothes obviously contaminated, are placed in a numbered bag. His boots are brushed with bleach solution, removed quickly, washed free of bleach with water, and then put in the bag with the outer clothing. This bag of clothing is sent at leisure to a laundry, the staff of which has been specially trained to handle it. Before the casualty passes on, any obvious splashes of gas on the skin are carefully removed by dabbing the area with numerous swabs wet with a solvent. The lesion is then treated with anti-gas ointment number 2 (chloramine T in a vanishing cream base), which is applied with a wooden spatula. An alternative ointment is anti-gas ointment number 1 (bleach ointment). These ointments should not be applied if erythema is present, and bleach ointment should not be left on too long.

The casualty takes into the undressing room a small bag with the same number as the bag containing his outer clothes. Any valuables he may have are put into the smaller bag. A tally which is given the same number as his bags is hung around his neck. In the undressing room he is instructed to remove, as quickly as possible, the remaining clothing and his gas mask. The clothing is added to his small bag. Any liquid splashes not previously noticed are treated with ointment.

In the shower room the patient sits on a stool and, if the eyes have been contaminated by liquid mustard gas, they are irrigated with 2% sodium bicarbonate solution, delivered by rubber tubing from a suspended douche can; irrigation is not necessary for vapour contamination. The patient then takes a shower. Special attention is paid during the shower to cleaning the hair, the post-aural region, the axillæ, the natal cleft, the backs of the knees and the interdigital spaces. After the shower is finished, the patient picks up his bag and passes into the dressing room.

In this room he dries himself and puts on some clothing which is supplied for him. His name, address and similar particulars are taken from him, and he is given written instructions as to the method of decontaminating the contents of his small bag. This decontamination may not be necessary, but it is an additional precaution. The patient is given a fresh gas mask before leaving. He calls back subsequently to return the bag loaned to him and to claim his outer clothing.

Treatment of Mustard Gas Lesions of the Eyes.

In the treatment of the eyes, various lotions have been used for irrigation in the early stages. They include 2% sodium bicarbonate solution, 2% boracic acid solution, normal saline solution and clean water. Most investigators believe that the damage has been done by the time these lotions are used, and this may account for the fact that the various solutions are of about equal value. Some workers believe that irrigation should be used only when discharge is present.

If pain is troublesome, it is relieved by 0·5% solution of dionine. Cocaine is avoided on account of its tendency to accentuate the damage to the cornea. Paraffin drops are used to prevent the lids from adhering. Atropine is employed as a routine in all cases in which the cornea is affected.

If a mucopurulent exudate develops, antiseptic drops such as 2% argyrol are used. Dark glasses should be worn if photophobia is a prominent symptom. After the acute stage has passed, 0·25% zinc sulphate drops should be used daily.

Many patients, on account of the swelling of the lids and photophobia, are afraid that they will lose their sight, but they are reassured about this if the doctor merely opens their eyes.

Treatment of Mustard Gas Lesions of the Skin.

In the early stages of erythema, the skin should be washed with soap and water, and the pubic and axillary hair cut short. This is a safeguard against further contamination, as well as the first stage of the treatment of a fresh, potentially infected wound.

If the skin is unbroken, a mild antiseptic powder, such as that made with equal parts of zinc oxide, boracic acid, chalk and starch, is applied. Healing is usually relatively quick and uneventful.

If blisters are present, they should be emptied by means of a sterile syringe. The lesion is essentially a burn, and should be treated as such—that is, the cleaning should be thorough and followed by the use of coagulants, pressure dressings, or saline baths and *tulle gras*, according to the indications. The burns are usually only second degree, but sometimes the whole skin is involved and skin grafting is necessary. The newer knowledge of how to keep a wound sterile should prove as useful in the treatment of mustard gas injuries as it has in the management of wounds in general.

Treatment of Mustard Gas Lesions of the Respiratory Tract.

Discharge from the nose, accompanied by pain, is treated by frequent warm douching with 5% sodium bicarbonate solution. Laryngitis is relieved by the inhalation of friars' balsam. If bronchopneumonia develops it is treated as if it had arisen in the ordinary way. The use of sulphonamides should improve the results of treating this complication.

Results of Treatment of Mustard Gas Injuries.

In the Great War at least 75% of the more severe mustard gas casualties could be returned to duty within eight weeks, of which some two to three were spent in hospital. The remaining 25% required longer treatment, but only about 0·5% had to be discharged. With efficient prophylaxis and treatment, the death rate from mustard gas was only 2% of those affected.

As described before, troublesome keratitis is an occasional after-effect. There is no ground for the belief that gassing predisposes to pulmonary tuberculosis by direct chemical irritation, but bronchopneumonia, if it occurs, carries, as usual, some threat of permanent lung damage.

Functional disorders may follow gassing. The commonest are aphonia, photophobia and the effort syndrome.

Lewisite.

Lewisite is an arsenical compound which was developed as a poison gas towards the end of the Great War, and so has not yet been used in military operations. It is a vesicant and is very similar to mustard gas.

It is a liquid with a high boiling point, and so is classed as a persistent gas. It has a faint odour, qualitatively similar to that of geraniums. It is soluble in oils and ordinary organic solvents.

Lewisite shows some significant differences from mustard gas. It has a lower freezing point, so that it is less liable to solidify in cold weather. It hydrolyses rapidly in water, especially in the presence of alkali. On account of this, a 5% aqueous solution of sodium hydroxide is useful for destroying liquid splashes of lewisite.

Lewisite is irritant immediately it comes in contact with the skin. It can therefore be detected earlier than mustard gas. The lesions it causes are not so deep, and healing is more rapid. It produces general effects, in that it is absorbed from the blisters and causes arsenical poisoning.

The treatment of lewisite poisoning is similar, in both its prophylactic and curative aspects, to that of mustard gas. Bleaching powder does not oxidize lewisite readily, however, so that bleach ointment is quite ineffective against splashes of the liquid, and even bleach paste is much inferior to hydrogen peroxide. The hydrogen peroxide (twenty volumes) should be freely swabbed onto affected skin and then applied as a compress for a few hours. It should not be used for the eyes.

Phosgene.

Phosgene is the typical and most effective member of the asphyxiants. It is gaseous at ordinary temperatures, so that it is non-persistent. It has an odour of musty hay.

Pathological Effects of Phosgene.

Phosgene has an irritant action on the alveoli and terminal bronchioles. This results in pulmonary œdema, which is the basic functional disturbance. Pulmonary œdema has four main effects: (*a*) there is a reduction in blood volume, which causes a condition of shock; (*b*) there is embarrassment to the right ventricle, on account of the pulmonary obstruction; (*c*) the sudden hæmo-concentration in the lungs creates a tendency to pulmonary thrombosis; and (*d*) the coughing induced by the fluid causes rupture of pulmonary alveoli.

Clinical Picture of Phosgene Poisoning.

In patients exposed to high concentrations of gas, the onset of symptoms is rapid. The patient immediately suffers from irritation of the respiratory passages, accompanied by smarting and watering of the eyes. Coughing is induced, and there is pain in the chest. Nausea and vomiting often occur.

As pulmonary œdema increases, the breathing becomes rapid and shallow, and cyanosis develops. The cyanosis may be blue or grey; sometimes it changes from blue to grey. Blue cyanosis implies oxygen lack with carbon dioxide retention, the carbon dioxide acting as a vaso-

dilator. Grey cyanosis implies that the carbon dioxide is given off normally, but adequate oxygen is not being absorbed. This is the more serious condition, since, in the other case, retention of carbon dioxide helps by stimulating respiration. The probable explanation of the blue cyanosis is that obstruction to the pulmonary circulation is predominant, and the blood that passes through the lungs is insufficient either to take up enough oxygen or to give off the carbon dioxide produced in the tissues. In grey cyanosis the pulmonary exudation is the main factor. Pulmonary œdema does not interfere much with the giving off of carbon dioxide, since this gas is fairly soluble in the exudate. The œdema does, however, decrease the oxygen uptake and the blood volume. The importance of the distinction between blue and grey types of cyanosis is that venesection is helpful in the former, but harmful in the latter.

In contrast to these patients just described, those who are exposed to low concentrations of the gas show, at first, only trivial symptoms. Frequently they carry on with their work for two to six hours. Circulatory collapse may then be precipitated. The probable explanation is that some pulmonary exudation continues throughout the latent period, and eventually the compensatory forces are overcome. The taking of a meal often appears to be the factor which finally induces the breakdown.

The pulmonary œdema is detected by the frothy sputum and numerous râles. It may lead on to pulmonary infection, with rise of temperature.

Prophylaxis against Phosgene.

The gas mask gives complete protection. Unless small amounts of the gas are ignored, or large amounts are encountered so suddenly that the mask cannot be adjusted in time, casualties from phosgene amongst a properly equipped population should not be severe.

Treatment of Phosgene Poisoning.

The important measures are to provide rest, warmth and oxygen, and to subject those with blue cyanosis and raised venous pressure to venesection.

Even those who have been only moderately affected should rest, in order to prevent a subsequent onset of symptoms. The rest should be absolute. Sedative drugs such as barbiturates or bromide are useful, but morphine is usually avoided on the ground that it may depress the respiration. In the later stages sulphonamides may be required for pulmonary infection.

Oxygen should be administered continuously to patients with cyanosis, and will usually be required for a couple of days at least. This creates a tremendous problem in supplying sufficient oxygen for a large group of patients.

Venesection of 400 to 600 cubic centimetres of blood is indicated when venous engorgement is present.

Atropine has no effect on the exudation. The secretions inhibited by atropine do not contribute to the pulmonary œdema.

Arseniuretted Hydrogen.

Arseniuretted hydrogen, or arsine, is an almost odourless, non-irritating gas which usually cannot be detected without the use of chemical methods. It can be disseminated from cylinders, or generated by the action of dew or rain on calcium arsenide that has been sprinkled in the form of a fine powder.

Arsine exerts its toxic effect by causing hæmolysis of red blood cells. The hæmolysis may continue for several days and the resulting anæmia be very severe. The hæmoglobin liberated gives rise to jaundice and may also cause anuria.

The symptoms are shivering, weakness, giddiness, headache, vomiting and breathlessness on exertion. Hæmoglobinuria and anæmia are found, and anuria may supervene in severe cases.

The condition, if severe, is treated by blood transfusion, given slowly. The urine should be kept alkaline, and fluids freely administered so that renal failure is made less likely.

Hydrocyanic Acid.

Hydrocyanic acid is a clear colourless liquid of low boiling point. It is rather lighter than air, and so diffuses very readily.

In high concentrations it is rapidly fatal, owing to the fact that it inhibits tissue oxidation. In open warfare, however, it has not been possible so far to secure high concentrations, because the properties of the gas are not suitable. Small amounts may produce headache, giddiness, nausea and inability to concentrate. Some respirators are not effective against hydrocyanic acid, but special types give full protection.

Hydrogen Sulphide.

Hydrogen sulphide is a colourless gas with a fœtid odour. High concentrations kill within a few minutes. Lower concentrations act as an irritant and, in addition, poison the enzyme systems controlling tissue oxidation. The gas was used on a small scale in the Great War.

The respirator is effective against hydrogen sulphide. In mild cases symptomatic treatment is used, and in severe cases artificial respiration is carried out.

Lachrymators.

Lachrymatory properties are associated in many cases with the presence of a halogen group. The chief substances concerned are chloracetophenone (C.A.P.), ethyl iodoacetate (K.S.K.) and bromobenzyl cyanide (B.B.C.). They are effective in low concentration.

The most prominent effect is acute irritation of the conjunctiva with profuse lachrymation and blepharospasm. The eyelids do not become swollen. If the concentration is high, a burning sensation is felt in the throat and, if the exposure is continued, nausea and vomiting may result. Chloracetophenone also irritates the skin.

These gases are used as harassing agents. They compel those who are attacked to wear respirators.

Treatment consists in irrigation of the eye with 2% sodium bicarbonate solution or 3% boric acid.

Sternutators.

Sternutators are mainly arsenical compounds which can be dispersed by detonation in the form of clouds of fine particles. The chief are diphenylchlorarsine (D.A.), diphenylaminechlorarsine (D.M.) and diphenylcyanoarsine (D.C.). When inhaled, they cause acute pain in the nose, fullness in the head, and sneezing. Mental distress is very marked in severe cases.

The modern respirator protects against these gases. Active treatment is rarely necessary for those who have been exposed. If required, 5% solutions of sodium bicarbonate will allay the nasal irritation.

Other Gases.

There is always a danger that new gases may be developed, or more effective methods found for the dissemination of the well-known gases. The ideal chemical for offensive warfare, however, must combine many qualities: it must be very toxic, even at high dilutions; it must be capable of manufacture from available raw materials; it must be fairly stable and non-corrosive; it must not be too light, and it should be able to be liquefied. Powerful gases are already known, and it may prove more profitable to improve the methods of dispersing them rather than to attempt to replace them.

The Detection of War Gases.

For practical purposes, great reliance has to be placed on the educated sense of smell. Chemical detectors are available for many individual gases, and attempts, which have so far proved of doubtful value, have been made to produce an automatic detector, working on a system of pH and oxidation-reduction indicators.

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